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Fault Detection of Shadow Mask by Use of Spatial Filtering

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Abstract In KACC'91 and '92 conference, we proposed a method of automatically detecting the shape of the faulty holes in a shadow mask by use of CCD camera and image data processing technique. In this method, two adjoining test areas from one image data of the shadow mask are taken and comparing the shape of holes in these two areas, we can detect the faults in the shadow mask.

In this paper, a method is described by use of spatial filtering of effectively finding the faulty holes from the difference image data between the two tested image data. The main role of the filter is to remove sampling errors occurring at the edge of the holes. And the second role is not only to find the existence of faulty holes but also exactly express the shape of faulty holes.

Computer simulations and actual experiments with shadow masks have shown that this method of fault detection is very effective for practical use.

1 Introduction

A shadow mask used in a cathode-ray tube of a color television is made from a thin iron plate in which several hundred thousands of small holes exist. These small holes are made through a photo etching process. In the process of making such a shadow mask, there occurs the case where some of those holes have not correct size and shape, which causes color blur on the screen of color TV. So it is an important task to automatically detect and eliminate those faulty shadow masks.

But even in these days, the detection and elimination of such faulty holes are done by human eyes, causing much cost and heavy labor.

This paper describes a method of automatic detection of shape of the faulty holes by use of CCD camera and image data processing. In this method, two image data are taken from two adjoining test areas from one image data of the shadow mask with CCD camera.

Comparing the shape of holes in these two adjoining test areas, we can find any fault in the shape of holes. Specifically, the outline of this method is described as follows.

1. The two-dimensional crosscorrelation function between the data of two test areas is first calculated.
2. And then we move one of the image data to the place where the crosscorrelation function becomes maximum.
3. Then we subtract one of two image data from another.
4. The subtracted image data include the information of faulty holes and sampling error occurring at the edge of the holes.
5. The effect of spatial filtering is described for finding the only faulty holes from the subtracted image data.

From the results of the experiment, this method of fault detection of a shadow mask is expected to be used widely in shadow mask industries.

2 Observed image data

When the shape of holes of a shadow mask is observed with a microscope, the shapes of the holes are converted into the pattern of black and white.

This pattern is observed with the CCD camera and converted to the image data, which are fed to a personal computer. The image data is then converted into binary data.

When the shape of the hole of the shadow mask is circular, the image data becomes as shown in Fig. 1.

The image data are taken from two adjoining test areas of the shadow mask as shown in Fig. 2 (a) and (b). Comparing the shape of holes in these two test areas, we can find any fault in the shape of holes.

Fig. 1 shows the data containing a faulty hole. These image data are compared with the data having only normal holes, then we can find fault in the shape of holes.

Directly comparing the two independent image data requires accurate positioning of the shadow masks, whereas comparing two image data as shown in Fig. 2 (a) and (b) has the advantage that the shadow mask need not be put in accurate position.

When the normal image data obtained from normal holes are represented as $x_n(k,l)$ where k and l are x and y variables on the screen, and the faulty image data obtained from the area containing faulty holes are represented as $x_f(k,l)$, $x_f(k,l)$ are written as follows.

$$\begin{aligned} x_f(k,l) &= x_n(k,l) + d(k,l) \qquad (1) \\ k,l &= 0,1,2,\ldots,N-1 \end{aligned}$$

where $d(k,l)$ represents fault.

3 Detection of fault by subtraction of the two image data

We have developed a method of fault detection by use of correlation function and subtraction.

The two-dimensional crosscorrelation function between image $x_n(k,l)$ and $x_f(k,l)$ is assumed to be $R_{nf}(m,n)$. Then

$$\begin{aligned} R_{nf}(m,n) &= \sum_{k=0}^{N-1}\sum_{l=0}^{N-1} x_n(k,l)x_f(k+m,l+n) \\ m,n &= 0,1,2,\ldots,N-1 \qquad (2) \end{aligned}$$

The phase that the maximum crosscorrelation function is obtained is assumed to be m' and n'. Then by moving the image $x_f(k,l)$ to (m',n') position, two images $x_n(k,l)$ and $x_f(k,l)$ almost coincide.

That is, the two test areas are overlapped so that the two-dimensional crosscorrelation function may become maximum. So the difference image $D(k,l)$ is obtained as follows.

$$\begin{aligned} D(k,l) &= \begin{cases} \mid x_n(k,l) - x_f(k+m',l+n') \mid \\ (\,if\ 0 \le (k+m'),(l+n') < N\,) \\ 0\ (\text{otherwise}) \end{cases} \\ k,l &= 0,1,2,\ldots,N-1 \qquad (3) \end{aligned}$$

The subtracted image data are shown in Fig. 3.

A thick circle in the subtracted image data shown in Fig. 3 is a fault, and dot circles in Fig. 3 are due to sampling error and are not faults. These sampling errors can be removed by use of a smoothing filter.

4 Use of spatial filtering

In this method, it can be said that the shape of a hole of shadow mask is tested by comparing with those holes existing in the neighborhood. The image data obtained from the difference in two adjoining test areas include images which include faults.

In KACC '92 conference, we proposed two methods of smoothing filter by use of Median filtering and Contraction and Expansion processing.[2] The spatial filtering methods described in the following section are better in computation time than the previous methods.

Faults are defined here as those in which the length of holes deformed by more than 10% from the standard values, that is, the difference image is considered to be fault when the number of pixels in the lateral direction exceeds f_x, and the number of pixels in longitudinal direction exceeds f_y. Here we call f_x and f_y as a judgement criteria.

We have tested two spatial filtering for obtaining the faulty image.

4.1 Spatial filtering 1

The first spatial filtering is as follows. Two judgement image 1 and 2 are first made for lateral and longitudinal directions, and then these two judgement images are taken logical AND.

The judgement image 1 is made according to the judgement criteria f_x in lateral direction, and the judgement image 2 is made according to the judgement criteria f_y in longitudinal direction.

The judgement image $h(k,l)$ by the logical AND of these judgement image 1 and 2 is made by Equation (4).

$$h(k,l) = \begin{cases} 1 & (if\ D(k,l)=1 \\ & and\ D(k,l+f_x)=1 \\ & and\ D(k+f_y,l)=1) \\ 0 & (\text{otherwise}) \end{cases}$$
$$k,l = 0,1,2,\ldots,N-1 \qquad (4)$$

where $h(k,l)=1$ represents fault.

An example of the judgement image processed by this method is shown in Fig. 4.

In the judgement images shown in the * marks show the remaining pixels as pixel=1, and ○ mark show the pixels eliminated as pixel=0.

In this judgement image, ○ mark in one ring form (left side of Fig. 4, normal hole) showing the sampling error have been all eliminated. The images in the ring form having some width are the images that should be judged as faults.

Fig. 6 (a) shows the difference image data and Fig. 6 (b) shows the judgement image being processed with the spatial filtering 1.

4.2 Spatial filtering 2

The judgement image with the spatial filtering 1 shows only the presence of faults and not the true shape of the fault. So the following processing is carried out.

When faults exits according to the judgement criteria f_x in lateral direction, the image data within f_x are left as they are.

Besides, when faults exits according to the judgement criteria f_y in logitudinal direction, the image data within f_y are left as they are.

The judgement image $h(k,l)$ by the logical AND of above two images is made by Equation (7). k_p and l_p represents position of respective pixels.

For $l_p \le l \le l_p + f_x$

$$u(k,l) = \begin{cases} D(k,l) & (if\ D(k,l)=1\ and \\ & \quad D(k,l+f_x)=1) \\ 0 & (\text{otherwise}) \end{cases} \qquad (5)$$

For $k_p \leq k \leq k_p + f_y$

$$v(k,l) = \begin{cases} D(k,l) & (if\ D(k,l) = 1\ and \\ & \quad D(k+f_y,l) = 1) \\ 0 & (\text{otherwise}) \end{cases} \quad (6)$$

From Equation (5) and (6),

$$\begin{aligned} h(k,l) &= u(k,l) \wedge v(k,l) \qquad (7) \\ k,l &= 0,1,2,\ldots,N-1 \end{aligned}$$

The results of the processing by this method are shown in Fig. 5. In this judgement image, the images in the ring form having a certain width which show faults, are preserved as * marks.

That is, not only the presence of faults, but also the shape of the faults in the image data of difference is obtained accurately.

The images shown in Fig. 7 (a), (b) are the original image data of difference and the judgement image processed with the spatial filtering 2.

5 Conclusion

In the proposed method of automatically testing the faults in the shape of the holes of shadow masks, two parallel test areas are extracted in the observed image by using a CCD camera, and by use of correalation technique, the image data of the difference between them are made.

This image data of the difference include the information on the faults of holes and the sampling error arising at the edge part of the holes.

Therefore, by applying the smoothing processing, only the images showing the faults are displayed.

The smoothing processing is better by spatial filtering 2, and the results obtained by this method showed not only the presence of faults in a certain criteria, but also that the accurate shape of the holes.

As the experimental results show, the method of detecting the faults in the holes of shadow masks proposed here seems to be useful for practical applications.

References

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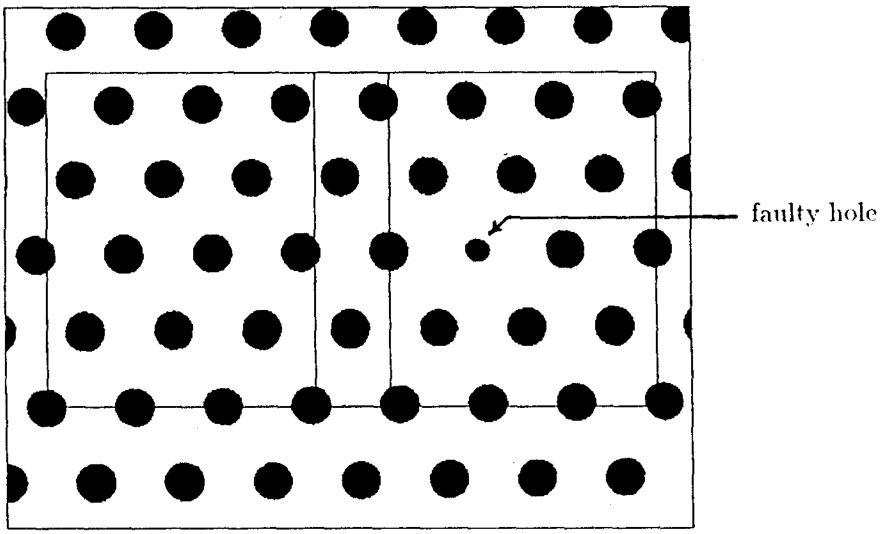

Fig. 1 Observed area (include two test areas)

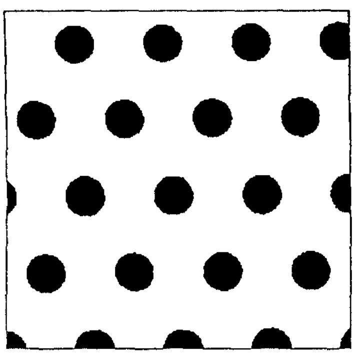

Fig. 2 (a) Test area 1

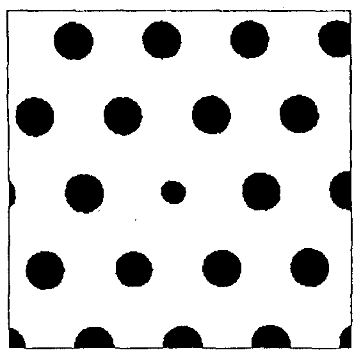

Fig. 2 (b) Test area 2

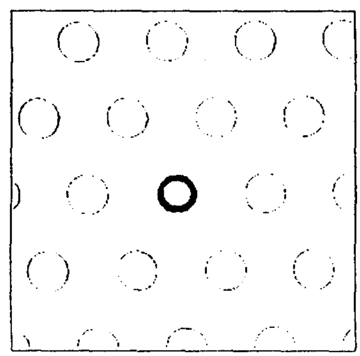

Fig. 3 Difference image

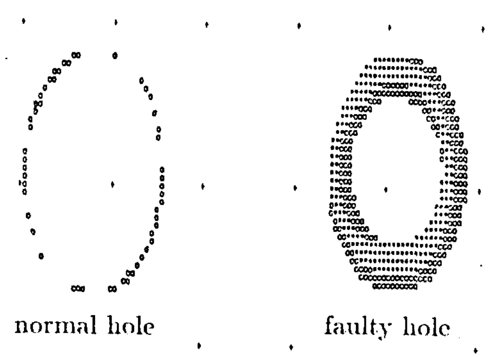

Fig. 4 Judgement image
by spatial filtering 1

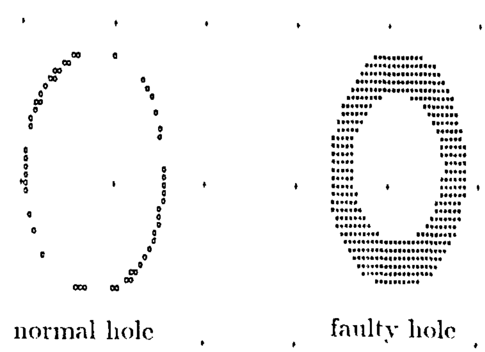

Fig. 5 Judgement image
by spatial filtering 2

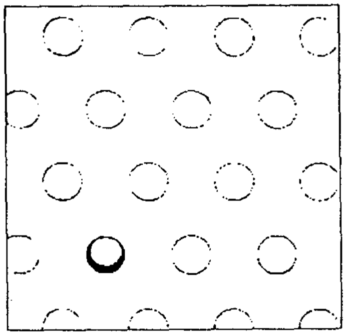

Fig. 6 (a) Difference image

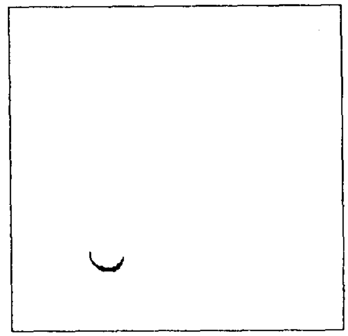

Fig. 6 (b) Judgement image by spatial filtering 1

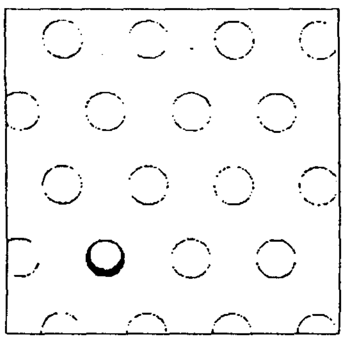

Fig. 7 (a) Difference image

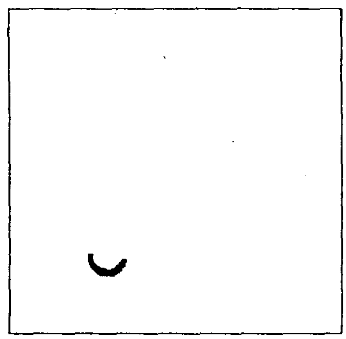

Fig. 7 (b) Judgement image by spatial filtering 2